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## Fungal Influenced Corrosion of Metals in Humid Environments

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### ABSTRACT

Case studies of atmospheric corrosion will be reviewed in which fungi produced localized corrosion of bare metals and disbonding of coatings. In relative humidities of 65% or greater with adequate nutrients, fungi can thrive and produce acidic by-products, including oxalic, lactic, acetic, and citric acids. Fungi can derive nutrients from soil; cellulosic materials (grains, paper, composition board, and wood); hydrocarbons (crude oil, fuel oil, jet fuel, kerosene, greases, waxes, lubricants, and adhesives); organic coatings and numerous other sources. Case studies will identify causative organisms, sources of nutrients, corrosion mechanisms, and possible remedies.

### INTRODUCTION

Liquid water is needed for all forms of life and availability of water influences distribution and growth of microorganisms. Water availability can be expressed as equilibrium relative humidity or water activity ( $a_w$ ) with values ranging from 0 to 1. Microbial growth has been documented over a range of  $a_w$  from 0.60 to 0.999<sup>1</sup>, though none can grow at  $a_w = 1$  (pure water) because there are no nutrients available to the organism. Fungi are the most dessicant-resistant microorganisms and can remain active down to  $a_w = 0.60$  whereas few bacteria remain active at  $a_w$  values below 0.9.<sup>2</sup> Fungi are nonphotosynthetic organisms, having a vegetative structure known as a hyphae, the out-growth of a single microscopic reproductive cell or spore. A mass of threadlike hyphae make up a mycelium (Figure 1).<sup>3</sup> Mycelia are capable of almost indefinite growth in the presence of adequate moisture and nutrients so that fungi often reach macroscopic dimensions. Yeasts are fungi that multiply by forming buds instead of mycelia. Fungi are ubiquitous in atmospheric and aquatic environments. Spores, the non-vegetative dormant stage, can survive long periods of unfavorable growth conditions, e.g., drought and starvation. When conditions for growth are favorable, spores germinate.<sup>4</sup>

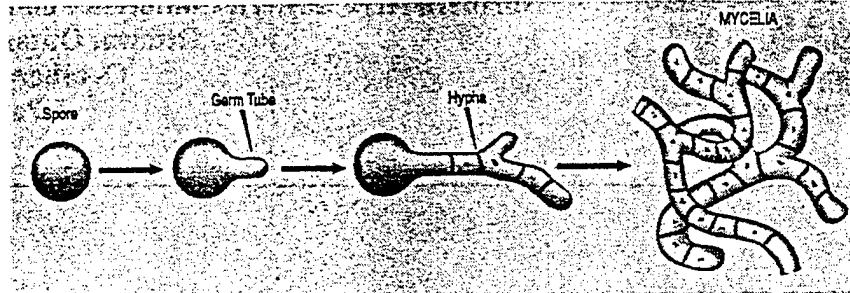


FIGURE 1- Growth stages of filamentous fungi.

Biodeterioration due to fungi has been documented for the following: cellulosic materials (paper, composition board and wood); communication wire; cable splices; telephone cable; cable sheaths; photographic film; polyvinyl chloride films; sonar diaphragm coatings; map coatings; paints; metals; crude oil; fuel oil; jet fuel; kerosene; greases; waxes; lubricants; adhesives; asphalt; hydraulic fluids; rain repellents; textiles (cotton and wool); vinyl jackets; leather shoes; feathers and down; natural and synthetic rubber; optical instruments; mechanical, electronic and electric equipment (radar, radio, flight instruments, wire strain gages, helicopter rotors); hammocks; tape; thermal insulation; brick masonry and concrete; medicines; and museum valuables. Most documented cases of fungal induced biodeterioration involve materials other than metals or metals exposed in aquatic or fluid environments. For example, despite the extensive data base that has been developed on biodeterioration and biocides, fungi remain a modern problem for production, transportation, storage and use of hydrocarbon fuels contaminated with even small amounts of water as documented by Videla<sup>5</sup> and others.<sup>6-7</sup> Stranger-Johannessen<sup>8</sup> reported deterioration of the epoxy resin coating of ship holds filled with molasses, fatty oils and other fluid cargoes. She also confirmed fungal degradation of polyurethane cable sheathing in the marine environment.<sup>9</sup> There are fewer documented case histories of fungal influenced corrosion of metals in humid atmospheric conditions. Geesey<sup>10</sup> discussed potential fungal-induced corrosion for metal containers selected for storage of nuclear waste in terrestrial environments. The following are documented case histories of fungal influenced corrosion of metals in humid environments.

### Wire Rope

Corrosion inspection statistics compiled for 117 spools of wire rope used in military applications indicated that five of 58 highlines stored indoors showed some sign of corrosion whereas 42 of the 59 spools stored outdoors were unsuitable for use because of localized corrosion.<sup>11</sup> Time in storage was not a factor. The 1-inch carbon steel wire ropes used in military applications are prepared with six individual strands around an independent wire core coated with a thick maintenance grease and threaded onto wooden spools (Figure 2a) that are wrapped in brown paper & black plastic prior to storage. Wire rope

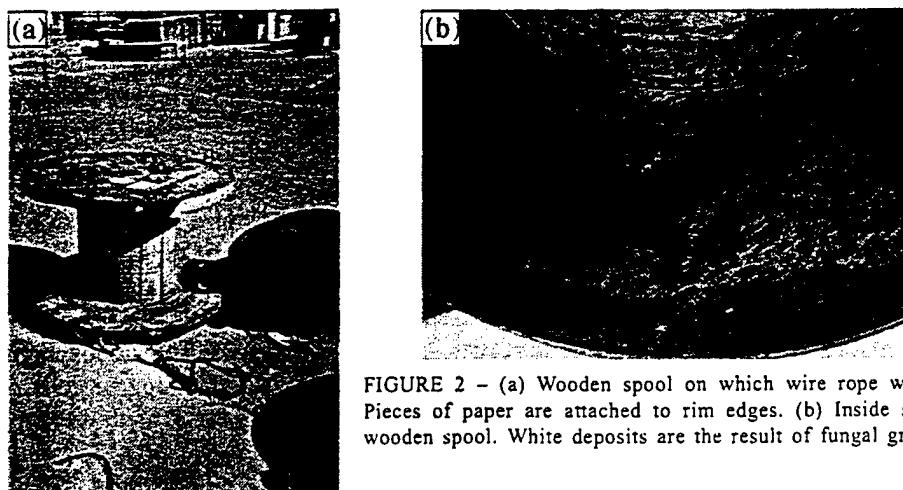


FIGURE 2 – (a) Wooden spool on which wire rope was stored. Pieces of paper are attached to rim edges. (b) Inside surface of wooden spool. White deposits are the result of fungal growth.

may be stored for weeks to months before being used. Any visible sign of corrosion means that the rope cannot be used for its intended purpose. Fungal growth was observed on interiors of some wooden spools stored outdoors (Figure 2b) and corrosion was most severe on wraps of wire in direct contact with the wooden spool flanges. There were numerous reports of a musty odor associated with spools when plastic packaging was removed. *Aspergillus niger* and *Penicillium* sp. were isolated from wooden spool flanges. Isolates could not be maintained on the protective grease, i.e., these fungi could not break down the maintenance coating to obtain nutrients. Instead fungi growing on wood produced copious amounts of CO<sub>2</sub>. The pH of condensate monitored using a microelectrode with a tip diameter of 2.4 mm (Microelectrodes Inc., Londonderry, NH) was consistently below 5.0. In laboratory experiments, *Aspergillus niger* produced localized corrosion when there was direct contact between wire rope and inoculated wood on potato dextrose agar (PDA) (Figure 3a,b). Acidic condensate dissolved the maintenance grease and also produced localized corrosion.

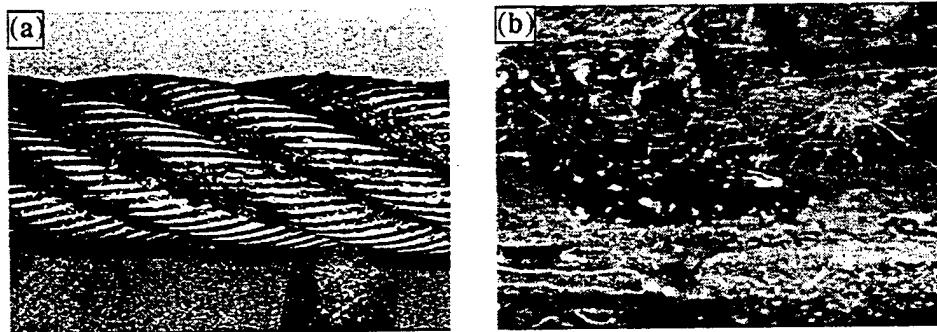


FIGURE 3 – (a) Wire rope that had been in contact with wood and PDA inoculated with *Aspergillus niger*. Rope rolled aside to show localized corrosion after contact with agar or wood. (b) Fungal mycelia with corrosion products (8x).

Laboratory data and field statistics implicated the practice of storing carbon steel highlines in humid conditions wrapped in plastic with microbiologically influenced corrosion (MIC). The replacement of plastic wrapping with paper packaging and redesign of wooden spool flanges to include slats one-half inch apart to promote ventilation are currently being evaluated as corrosion control measures. One hundred and forty-three new highlines manufactured in exactly the same way as previously described are being monitored. Six of seven spools wrapped in plastic and stored outdoors showed signs of localized corrosion after 2 months. There have been no reports of localized corrosion on redesigned spools stored outdoors where plastic wrap was replaced with paper.

### Microfungal Degradation of Painted Surfaces

#### *Military Helicopters*

Numerous reports document fungal growth in passenger compartments of in-service aircraft coated with polyurethane paint (Figure 4). A report by Lavoie and Little<sup>12</sup> documented the following eight fungal genera associated with H-53 aircraft: *Pestalotia*, *Trichoderma*, *Epicoccum*, *Phoma*, *Stemphylium*, *Hormodendrum* (also known as *Cladosporium*), *Penicillium*, and *Aureobasidium*. Representative culture



FIGURE 4 – Interior of H-53 helicopter with luxurious fungal growth on polyurethane paint.

plates indicated that several fungal species were co-located. Distribution of organisms was not limited to standing water/fluids. Organisms were cultured from virtually all interior surfaces, including primer-coated and polyurethane-coated 2024 T-6 aluminum, fiberglass structural members, caulking, synthetic fabrics, wiring and air-conditioning ducts. Concentration of organisms did depend on the availability of nutrients and water. Fungi were more numerous in low areas and occluded spaces holding water or hydraulic fluid. Fungi appear to be able to use hydraulic fluid and lanolin as a source of nutrients, but neither appears to be the source of the fungi. The topcoat of a piece of peeling paint was uniformly colonized by fungi (Figure 5a-c). Environmental scanning electron microscopy was used to demonstrate that the fungus penetrated the coating and caused disbonding between topcoat and primer. Glossy finish polyurethane fouled more readily than did the same formulation with a flat finish. Aged paint fouled more rapidly than new coatings. Laboratory tests demonstrated that in the presence of hydraulic fluid or lanolin, most of the isolates caused localized corrosion of bare 2024 T-6 aluminum (Figure 6).

## CONCLUSIONS

The possibility of fungal-influenced corrosion of metals in humid environments has enormous economic consequences. In relative humidities of 60% or greater with adequate nutrients, fungi can thrive and produce acidic by-products that cause corrosion of bare metals and disbonding of coatings on coated metals.

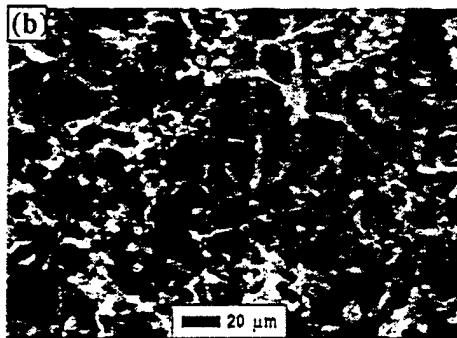
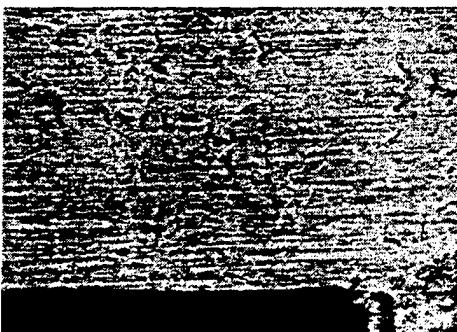


FIGURE 5 - (a) *Aureobasidium* sp. on exterior of polyurethane paint, causing disbonding. (b) Micrograph of *Aureobasidium* sp. (c) Underside of disbonded paint chip.

FIGURE 6 - Fungal-induced corrosion of bare 2024 T-6 aluminum.



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